attended by sufficient duration of warmth to thaw the ice, is even more disastrous, unless the flow can be regulated to allow all water to pass under the ice.

The daily publications and reports of the Weather Bureau, especially the forecasts, are utilized freely in the consideration of this daily problem of water regulation, the superintendent of power having made intensive use of the weather map until it was suspended during the war, in amplifying the general forecasts for the specific problems in his own region. During the past winter (December, 1918, to March, 1919, inclusive) the State forecasts were amplified at the Salt Lake City office of the Bureau for the Bear River region, and the conditions prevailing over the northwestern States were given to the officials of the company by telephone each morning for their consideration in the water regulation problem.

THE COLORADO RIVER.

By FREDERICK H. BRANDENBURG, District Forecaster.

[Dated: Weather Bureau, Denver, Colo., July, 1916.]

SYNOPSIS.—This paper concerns the method of river-stage forecasting for the Colorado River and its principal tributaries, the Green, Grand, and San Juan Rivers. A brief description of the topographic features and courses of these streams is given. Attention is given to temperature conditions, as these to a large extent control the melting of the snows, which in turn make up much of the water supply. Two rating tables supplement the text, covering the Green and the Grand Rivers, respectively.—H. L.

The Colorado River is formed by the junction, in southeastern Utah, of the Green and Grand Rivers, and is joined by the San Juan River, its most important tributary, a few miles north of the Arizona-Utah State line. (See Fig. 1.)

The Green River rises in the mountains of southwestern Wyoming, and thence flows southward. From its source to its junction with the Grand River the Green is 425 miles in length. Near the Colorado-Utah State line it receives the waters of the Yampa and White Rivers, which drain northwestern Colorado.

The Grand River, which rises on the western slope of the Continental Divide in central Colorado, is joined by the Gunnison River at Grand Junction, Colo., and also by the Dolores, which drains the western slope of the San Juan Mountains, a short distance above the junction of the Grand and Green Rivers.

The San Juan, which rises on the southern slope of the San Juan Mountains, a part of the Continental Divide in southwestern Colorado, is about 200 miles in length.

In southeastern Utah and northern Arizona the Colorado River flows in a deep, rocky gorge, or canyon, through a region practically uninhabited, and the conditions are very similar along the Green and Grand Rivers for about 125 miles above their junction.

The drainage area of the Colorado River falls naturally into three divisions, the low-lying desert region, the elevated plateau region, and the mountain region. Each division has its characteristic climatic features. The lower division extends from the Gulf of California to the most easterly part of southeastern Nevada; the middle division from southeastern Nevada to the rating stations at Elgin, Utah; Fruita, Colo.; and Farmington, N. Mex.; and the upper division includes the area above such stations. The upper division is bordered on the north and east by the Continental Divide and on the west by ranges of high mountains.

The main flow of the Colorado comes, of course, from the snowfall in its upper reaches. The flow, however, is seldom large except during the periods of melting of the snow in the mountains. The summer rise usually occurs in June. The middle division contributes a considerable volume of water during March, April, and often during the first half of May from the melting of snow on the high table-lands. Practically no flow is received from snowfall in the lower division, although in the northern part of that division there are mountains which rise to an altitude of several thousand feet.

The mountainous nature of the country and the lack of telephone and telegraph facilities prevent the establishment of gaging stations on any part of the upper Colorado River. The usual method of predicting stages from gage readings at upstream stations on the same river is therefore out of the question, and results as unsatisfactory almost invariably attend an attempt to predict the stages of water on the main river from gage heights on the three rivers uniting to form it because they are so widely separated and their flow varies so greatly, a different method of arriving at results is necessary.

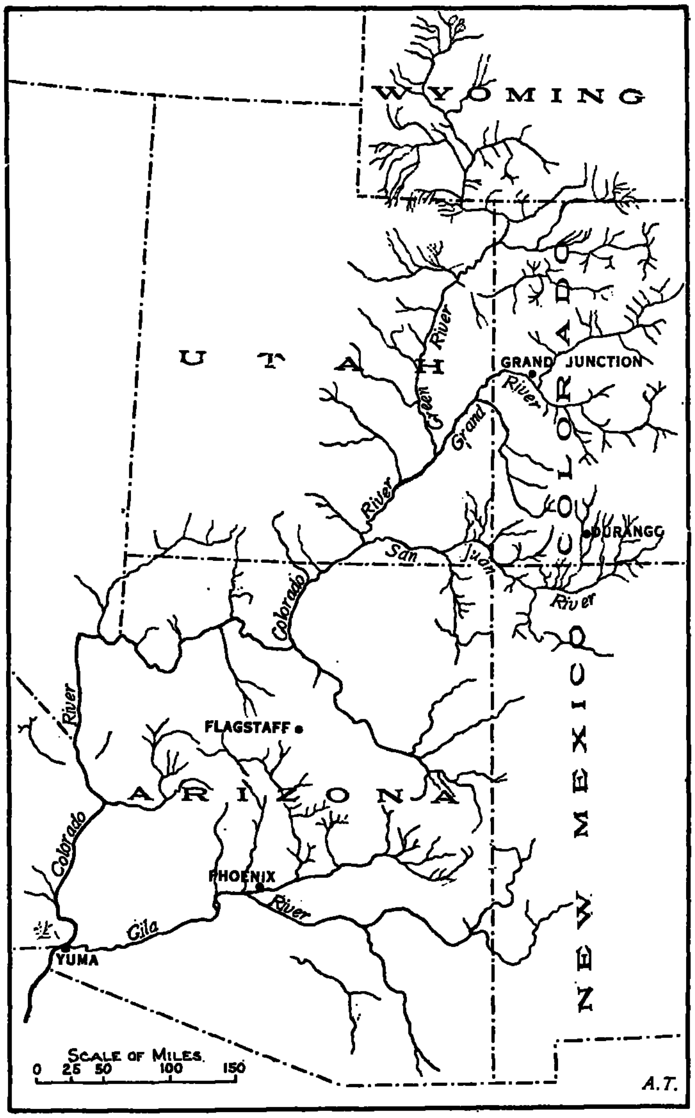

FIG. 1.

Temperature conditions as affected by different altitudes and the wide range in latitude through which the Colorado River and its tributaries flow control the melting of snow and affect the rate and date of the rise and the volume of water discharged. One tributary may be low, while the others are high at a corresponding time; another year the conditions may be directly the opposite. By combining the discharge the volume in cubic feet per second is the same as though the entire discharge were in one stream. Discharge measurements are made in the Grand River at Fruita, Colo., a few miles below the junction of the Grand and Gunnison; and on the Green River at Elgin, Utah. The discharge of the San Juan is estimated from the gage heights at a station near Farmington, N. Mex.

Usually there is an early and moderate crest in the lower trunk stream from the melting of snow in the middle division. As this area is below the rating stations, an estimate of the amount of this flow must be made and added to the combined discharge of the several tributaries at the rating stations above mentioned. After the middle of May the discharge of the Colorado River comes almost entirely from the upper division, simplifying the forecasting for the lower reaches.

Rating tables showing the discharge of the Green at Elgin and the Grand at Fruita, as determined by the Water Resources Branch of the United States Geological Survey, follow:

The tables give for each tenth foot on the gage the number of cubic feet of water per second passing the gage. In practice, in addition to the volume discharged by the Green and Grand, allowance is made for the discharge from the San Juan and the smaller tributaries. The distance from Elgin on the Green to Topock, Ariz., is about 760 miles. The elevation of Elgin is 4,044 feet and of Topock 456 feet—an average fall of 4.7 feet per mile. The distance from Fruita on the Grand to Topock is about 735 miles. The elevation of Fruita is 4,487 feet, making the average fall to Topock 5.5 feet per mile. The distance from Farmington, N. Mex., on the San Juan, to Topock is 690 miles. The elevation of Farmington being 5,240 feet, the average fall to Topock is 6.9 feet per mile. The distance from Topock to Yuma is about 165 miles; the elevation of Yuma is 137 feet, or an average fall of 1.9 feet per mile.

The average time for a crest to travel from Elgin to Topock is slightly in excess of six days; from Fruita, six days; and from Farmington slightly less than six days. In practice six days is used for the time interval for the combined discharges to reach Topock from Elgin, Fruita, and Farmington.

The average time for a crest to travel from Topock to Yuma is six days; but when there is sustained very high water upstream the maximum stage at Yuma is likely to occur as much as eight days later than at Topock.

During the greatest flood in the San Juan of which there is record or reasonably authentic information, the peak traveled from Farmington to Topock in four and one-half days, and from Topock to Yuma in three days. This flood occurred October 6, 1911, at a time of the year when the trunk stream is normally very low, and although much of the water was taken up by flooding of low ground adjacent to the river, the time interval was appreciably shorter than during the summer rises.

FORECASTING HIGH STAGES IN THE COLORADO RIVER.

Flood waves as commonly understood are the result of heavy rains. Heavy, general rains are unknown on the Green watershed, while heavy rains on the Grand watershed are local in character and unusual. The mountain region draining into the San Juan, however, is occasionally subjected to heavy downpours, causing destructive freshets. The bed of the main river can accommodate the largest freshets that occur in the Green, the Grand, or the San Juan singly, but when two of these rivers are in flood at the same time the lower river below the point of junction overflows its banks and causes damage. This condition occurs only as the result of the melting of heavy and general snowfall in the upper reaches.

Occasionally the measured discharge of the Colorado River at Yuma is less than the aggregate discharge of its tributaries at the gaging stations heretofore mentioned. The difference is in part due to the diversion of water for agricultural purposes under the Yuma reclamation project. As the maximum amount of these diversions is only about 6,000 second-feet, the cause of the smaller flow is most likely due to the temporary holding of the flood waters on the lowlands adjacent to the river, which are slow to return.

The time interval for crests increases with the flooding of the lowlands. Flood plains cover a large area in the lower division. For miles above the station at Topock the valley is 5 or 6 miles wide, and during freshets much of this area is covered by water, the overflow beginning when the gage at Topock is 11.5 feet; and when at 17 feet the river at Needles, Cal., 11 miles upstream, is 3 or 4 miles wide.

Another factor to be taken into account when forecasting river gage heights of the lower river is whether the season under consideration follows a year or two free from freshets. During prolonged periods of comparatively low stages of the water, the immense amount of silt brought down from the upper reaches, where the fall is great and the current swift, is deposited in the bed of the lower river where the gradient does not exceed 2 feet to the mile and the current is correspondingly sluggish. Under this condition the same volume of water causes a higher stage than it would if it had been preceded by a freshet during the same or even the preceding year. Scouring is rapid when the water is high. During the freshet of 1909 it is said the channel at Yuma was temporarily deepened 40 feet.

The following general principles are fairly well established:

The relation between the volume discharged and gage heights is close in extreme crests.

The time interval from the tributaries to the lower river is practically the same in extreme crests.

There is a flattening out of freshet waves before the lower river is reached.

The general rules which in practice have controlled forecasting of the stages of water in the lower reaches of the Colorado are as follows:

1. Expected gage heights at lower stations produced by combined discharge at rating stations above, have been determined.

2. Correction must be made for capacity of channel as affected by previous or absence of previous freshets, and also for amount of water likely to be contributed by the middle division.

3. The relation between gage readings and discharge at the rating stations above on the one hand, and the actual gage readings at the stations below on the other, as ascertained during the last preceding crest, deter-

mines the basis for the correction from the normal to be allowed.

4. The difference, if any, during the last preceding crest, between actual gage heights at lower stations and the expected heights at such stations must be considered and an allowance, corresponding to such difference, if any, made in the forecast.

5. If the combined discharge of the Grand, Green, and San Juan is in excess of 120,000 second-feet the time interval from these stations is one day longer for the crest at Topock and two days for the crest at Yuma.

6. There is generally a heavy run-off from the middle division before active melting sets in in the upper division, and accordingly from 10,000 to 20,000 second-feet are added to the upstream discharge in April and the early part of May, the amount depending on the preceding season's snowfall.

7. The time interval from the middle division to the stations in the lower division is four or five days.

8. When one crest follows another, the intervening period being too short for the submerged lands to drain, the time interval from the upper division to the lower division is reduced one or two days.

FALLING RIVER.

When falling stages occur in the upper reaches they are due to cooler weather or to the fact that the season's maximum of melting of snow has passed. The lower river falls rapidly as soon as the crest has passed. It is not unusual for the decline to equal 30,000 second-feet the first day and 20,000 second-feet the second and third days.

TABLE 1.—*Rating table*[1] *for Green River at Elgin, Utah, near Green River, Utah.*

Gage height.	Discharge.	Difference.	Gage height.	Discharge.	Difference.	Gage height.	Discharge.	Difference.
Feet.	*Sec.-ft.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Sec.-ft.*
6.00	3,300	300	9.40	18,900	600	12.80	43,600	800
6.10	3,600	300	9.50	19,500	600	12.90	44,400	800
6.20	3,900	300	9.60	20,100	600	13.00	45,200	800
6.30	4,200	300	9.70	20,700	600	13.10	46,000	800
6.40	4,500	300	9.80	21,300	600	13.20	46,800	800
6.50	4,800	300	9.90	21,900	700	13.30	47,600	800
6.60	5,100	320	10.00	22,600	700	13.40	48,400	800
6.70	5,420	340	10.10	23,300	700	13.50	49,200	800
6.80	5,760	360	10.20	24,000	700	13.60	50,000	800
6.90	6,120	380	10.30	24,700	700	13.70	50,800	800
7.00	6,500	400	10.40	25,400	700	13.80	51,600	800
7.10	6,900	420	10.50	26,100	700	13.90	52,400	800
7.20	7,320	420	10.60	26,800	700	14.00	53,200	800
7.30	7,740	440	10.70	27,500	700	14.10	54,000	800
7.40	8,180	440	10.80	28,200	700	14.20	54,800	800
7.50	8,620	460	10.90	28,900	700	14.30	55,600	800
7.60	9,080	460	11.00	29,600	700	14.40	56,400	800
7.70	9,540	460	11.10	30,300	700	14.50	57,200	800
7.80	10,000	500	11.20	31,000	700	14.60	58,000	800
7.90	10,500	500	11.30	31,700	700	14.70	58,800	800
8.00	11,000	500	11.40	32,400	800	14.80	59,600	800
8.10	11,500	500	11.50	33,200	800	14.90	60,400	800
8.20	12,000	500	11.60	34,000	800	15.00	61,200	800
8.30	12,500	500	11.70	34,800	800	15.10	62,000	800
8.40	13,000	500	11.80	35,600	800	15.20	62,800	800
8.50	13,500	600	11.90	36,400	800	15.30	63,600	800
8.60	14,100	600	12.00	37,200	800	15.40	64,400	800
8.70	14,700	600	12.10	38,000	800	15.50	65,200	800
8.80	15,300	600	12.20	38,800	800	15.60	66,000	800
8.90	15,900	600	12.30	39,600	800	15.70	66,800	800
9.00	16,500	600	12.40	40,400	800	15.80	67,600	800
9.10	17,100	600	12.50	41,200	800	15.90	68,400	
9.20	17,700	600	12.60	42,000	800			
9.30	18,300	600	12.70	42,800	800			

[1] The above table is not applicable for ice or obstructed channel conditions. It is based on three discharge measurements made during 1910 and the form of previous curves; one discharge measurement being made June 13, 1909, gage 15.15 feet, and is not well defined.

TABLE 2.—*Rating table for Grand River near Fruita, Colo.*

Gage height.	Discharge.	Difference.	Gage height.	Discharge.	Difference.	Gage height.	Discharge.	Difference.
Feet.	*Sec.-ft.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Sec.-ft.*
3.00	3,010	140	7.00	12,400	350	11.00	34,500	720
3.10	3,150	150	7.10	12,750	360	11.10	35,220	720
3.20	3,300	150	7.20	13,110	360	11.20	35,940	720
3.30	3,450	160	7.30	13,470	360	11.30	36,660	720
3.40	3,610	160	7.40	13,830	360	11.40	37,380	720
3.50	3,770	170	7.50	14,200	400	11.50	38,100	740
3.60	3,940	170	7.60	14,600	420	11.60	38,840	740
3.70	4,110	180	7.70	15,020	440	11.70	39,580	740
3.80	4,290	180	7.80	15,460	460	11.80	40,320	740
3.90	4,470	190	7.90	15,920	480	11.90	41,060	740
4.00	4,660	190	8.00	16,400	480	12.00	41,800	740
4.10	4,850	200	8.10	16,880	500	12.10	42,540	740
4.20	5,050	200	8.20	17,380	500	12.20	43,280	740
4.30	5,250	200	8.30	17,880	520	12.30	44,020	740
4.40	5,450	210	8.40	18,400	520	12.40	44,760	740
4.50	5,660	210	8.50	18,920	520	12.50	45,500	740
4.60	5,870	210	8.60	19,440	520	12.60	46,240	740
4.70	6,080	220	8.70	19,960	540	12.70	46,980	740
4.80	6,300	220	8.80	20,500	540	12.80	47,720	740
4.90	6,520	220	8.90	21,040	540	12.90	48,460	740
5.00	6,740	230	9.00	21,580	560	13.00	49,200	740
5.10	6,970	230	9.10	22,140	560	13.10	49,940	740
5.20	7,200	230	9.20	22,700	580	13.20	50,680	740
5.30	7,430	240	9.30	23,280	580	13.30	51,420	740
5.40	7,670	240	9.40	23,860	600	13.40	52,160	740
5.50	7,910	250	9.50	24,460	600	13.50	52,900	740
5.60	8,160	250	9.60	25,060	620	13.60	53,640	740
5.70	8,410	260	9.70	25,680	620	13.70	54,380	740
5.80	8,670	260	9.80	26,300	640	13.80	55,120	740
5.90	8,930	270	9.90	26,940	640	13.90	55,860	740
6.00	9,200	280	10.00	27,580	660	14.00	56,600	740
6.10	9,480	290	10.10	28,240	660	14.10	57,340	740
6.20	9,770	300	10.20	28,900	680	14.20	58,080	740
6.30	10,070	310	10.30	29,580	680	14.30	58,820	740
6.40	10,380	320	10.40	30,260	700	14.40	59,560	740
6.50	10,700	330	10.50	30,960	700	14.50	60,300	740
6.60	11,030	330	10.60	31,660	700	14.60	61,040	740
6.70	11,360	340	10.70	32,360	700	14.70	61,780	740
6.80	11,700	350	10.80	33,060	720	14.80	62,520	740
6.90	12,050	350	10.90	33,780	720	14.90	63,260	

WATER SUPPLY IN CALIFORNIA.

By ANDREW H. PALMER.

[Abstract: Journal of Geography, New York, Vol. xviii, No. 2 (Feb., 1919.)]

The author discusses both the present and the future water supply problem, with special reference to California.

The effect of the great latitude and topographic variation in the State is very marked on the rainfall—the real source of water power. The rainfall of California[1] presents some astounding contrasts. In the Mohave Desert, for example, the average annual precipitation is only 1 to 2 inches, while in portions of the Sierra Nevadas the annual amount exceeds 100 inches.

It has been found that in the central Sierras up to 5,000 feet elevation the average annual rainfall increases at the rate of 8.5 inches for each 1,000 feet.[2] Fortunately, much of the precipitation at the higher elevations is in the form of snow, thereby storing up water for power and irrigation purposes during the long rainless summers so characteristic of the Pacific coast States.

After taking up the natural controls of water power, namely, climate, topography, geology, vegetation, and artificial agencies (dams, reservoirs, etc.), the writer gives a brief history of hydro-electric development in California.

In conclusion, he discusses water power in relation to irrigation, flood control, and city water supply.

Thus, it is quite evident that of all the principal factors entering into the problem of water power and supply, climate, particularly precipitation, demands the first consideration.—*H. L.*

[1] *See* McAdie, A. G., The Rainfall of California, Univ. of Cal. pubs. in Geography, Berkeley, Calif., vol. 1, No. 4, February, 1914.

[2] Henry, A. J.: Increase of precipitation with altitude, MONTHLY WEATHER REVIEW, January, 1919, 47: 33-41. (2 figs.)